Rolls Royce IP-SOFC Technology Development

July 15th, 2009
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Senior Systems Specialist, Fuel Cell Development

Summary

- RRFCS has developed tools to characterize and improve our fuel cell technology
- Cell technologies are being developed by RRFCS which can meet performance and cost targets
- Scaled tests are demonstrating good performance and durability

Rolls Royce IP-SOFC Technology Development

- Technology and approach
- Cell performance testing and modeling
- Cell design improvements
  - Cell Pitch
  - Cell Materials
  - Primary Interconnect
- Cell performance and degradation

Rolls Royce IP-SOFC Technology Development

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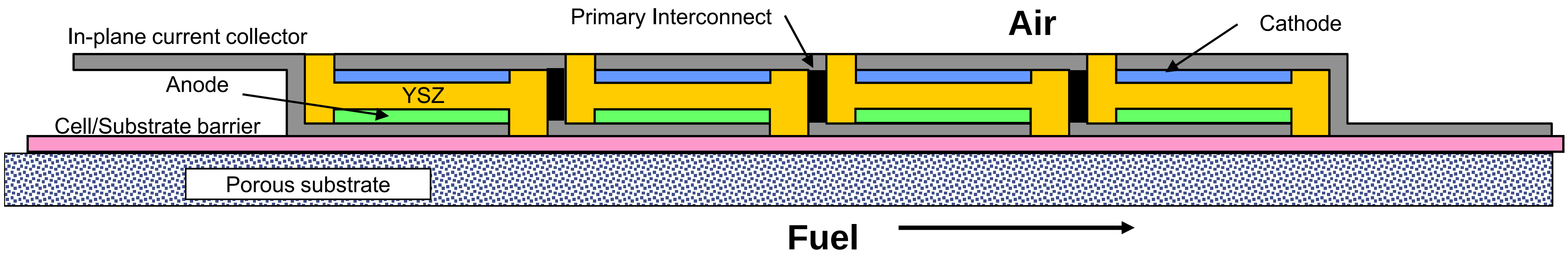
Rolls-Royce integrated planar solid oxide fuel cell tube

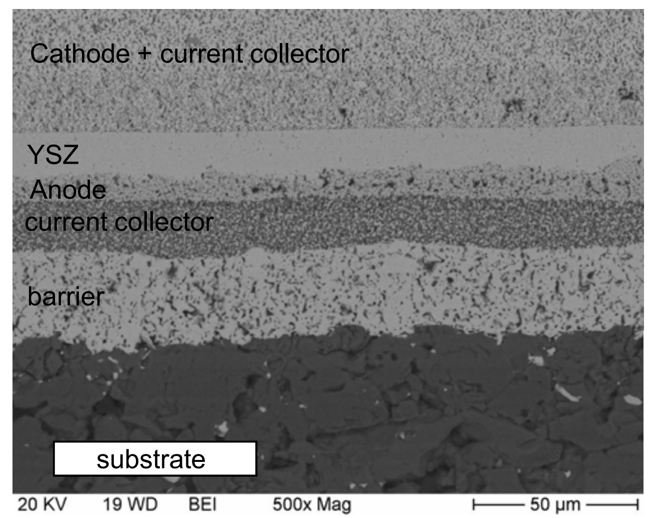


Integrated planar series arrangement

Series connected cell design for high voltage low current

Thin layers of active materials minimise cost

Ceramic support material uses low cost $MgO+Al_2O_3$ powder + low cost extrusion



High voltage low current benefits

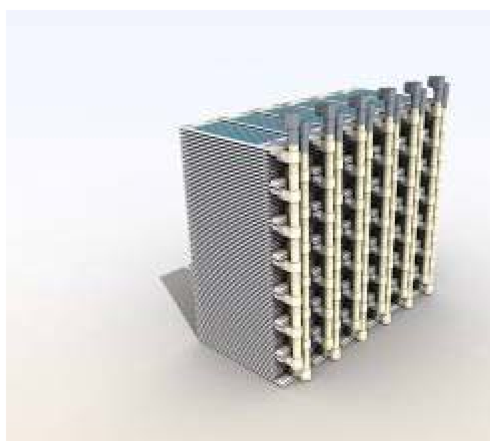
Easier hence cheaper for power electronics to convert low current DC to AC

High voltage facilitate direct conversion to 480 V AC grid requirement

Low currents give low Ohmic I^2R losses offering greater materials options

SECA

- **RRFCS is honored to be selected as an industrial team under the SECA program**
- **2010 targets**
  - **Degradation <2% / 1000 hours in 5000 hours demo test**
  - **15kW stack demonstration**
  - **System cost target for high volume production < $400/kW**



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Achieving the goal

- **High efficiency and low cost targets require focused optimization**
- **Detailed understanding of fuel cell performance drives improvements in cost and efficiency**
- **Cell development for performance improvement**
  - **Cell pitch**
  - **Current collectors**
  - **Electrode overpotential**
  - **Electrolyte**

SOFC Performance Model Development

Over-potentials (losses)

$$V_{cell} = E_{Nernst} - \eta_{ohmic} - \eta_{act,cathode} - \eta_{act,anode} - \eta_{conc,anode} - \eta_{conc,cathode}$$

Electronic Resistance (ohmic) | E-Chem Reactions (activation) | Mass Diffusion (concentration)

- Ohmic→ based on layer testing, confirmed by EIS
- Cathode activation
- Cathode concentration

  } based on cathode symmetric cell testing

- Anode activation
- Anode concentration

  } based on cell testing

Testing Performance Envelope

- Temperature (700 – 950ºC)
- Pressure (1 – 6.5 Bar_a)
- Cathode composition
  - Oxygen partial pressure (0.08 – 1 Atm)
  - CO_2 and H_2O additions
- Fuel composition
  - Bundle inlet to bundle outlet
  - Fuel dilution to observe anode mass diffusion limitations

Testing Capability

- 5 pressurized, 8 atmospheric test stands with system relevant gas compositions
- 10 atmospheric tube/bundle test stands
- 2 pressurized bundle test stands
- 4 block test stands under build/commissioning

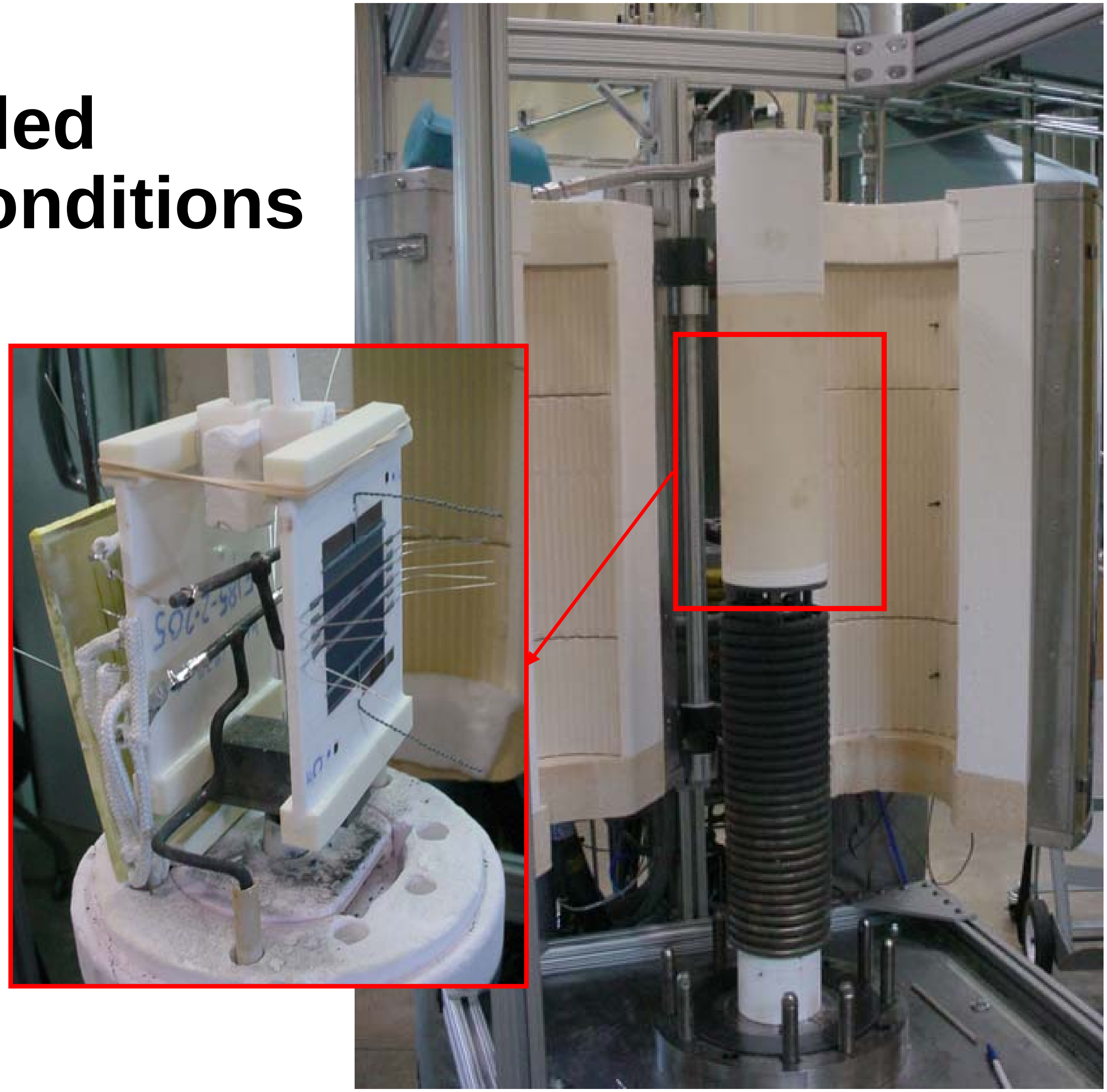
Well Controlled Boundary Conditions

Pressure

Temperature

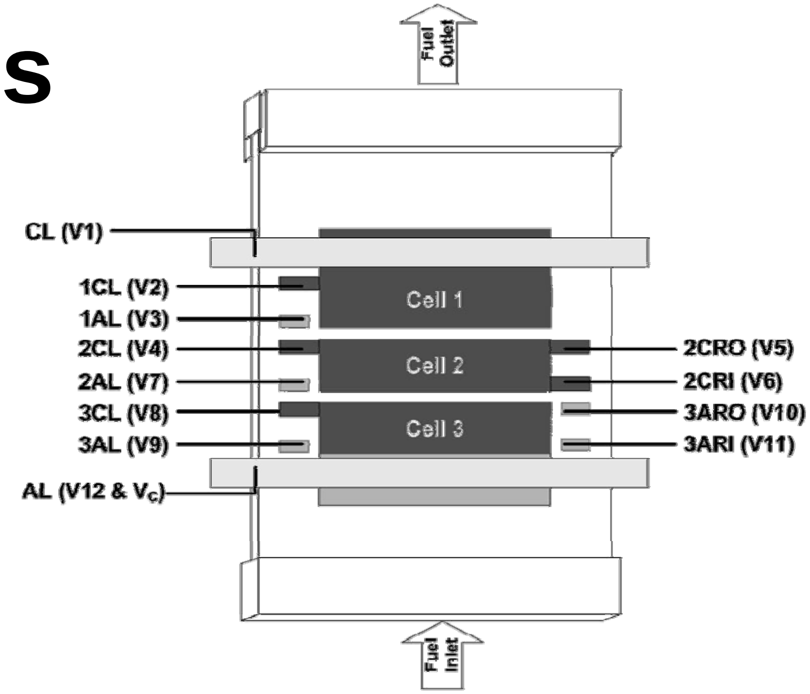
Current/Voltage

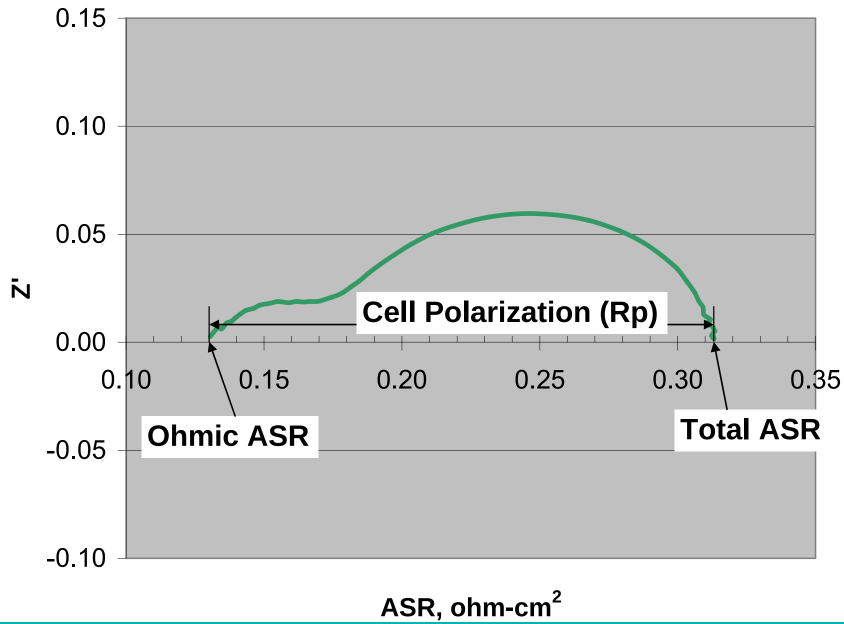
Composition

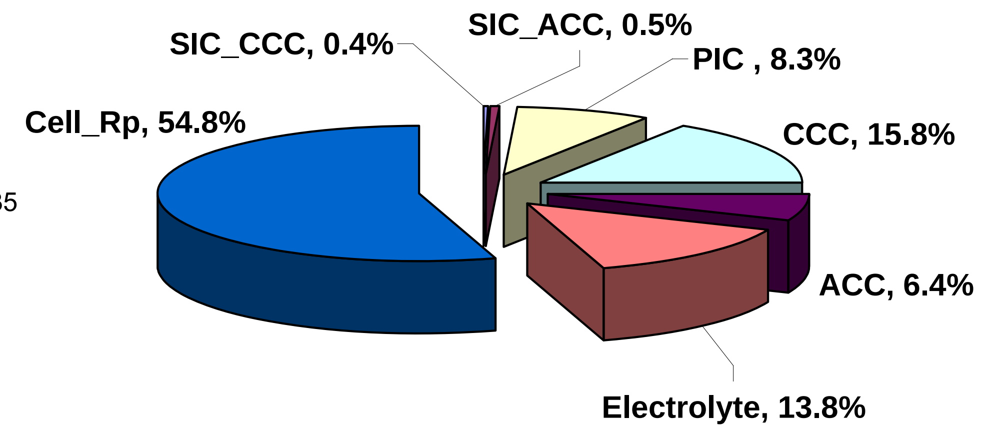


Detailed Cell Analysis

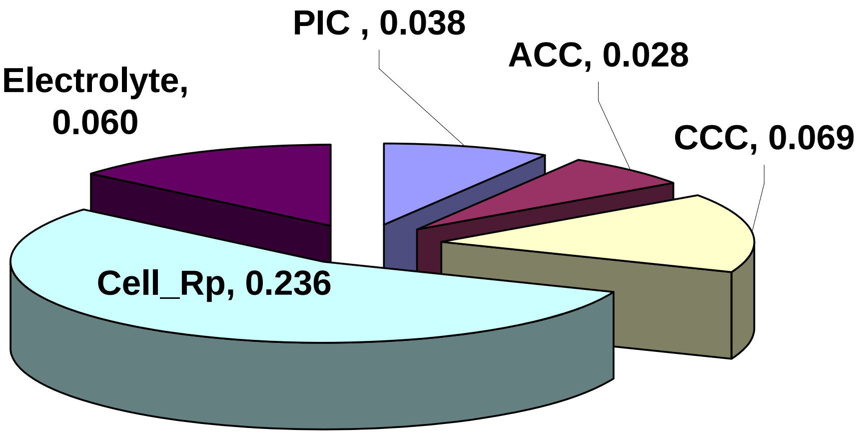
- Voltage taps to discretize cell losses
- EIS to interrogate e-chem

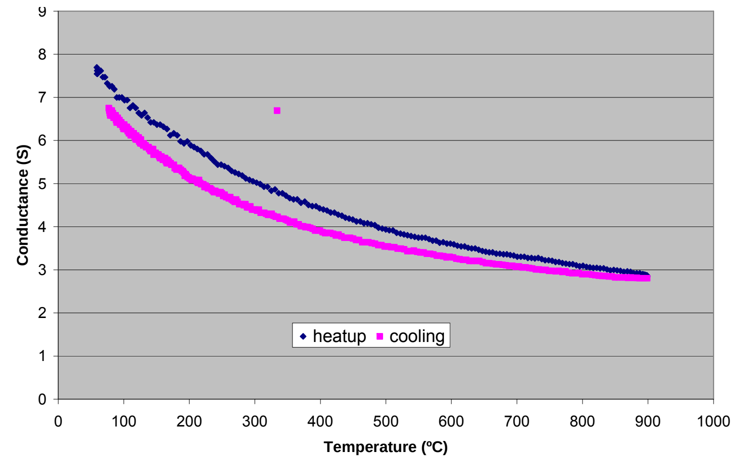






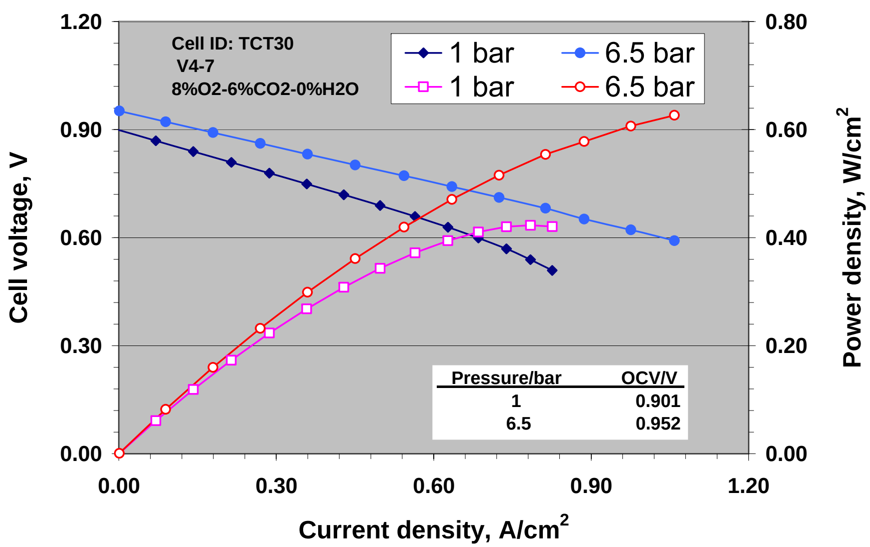
Model Development

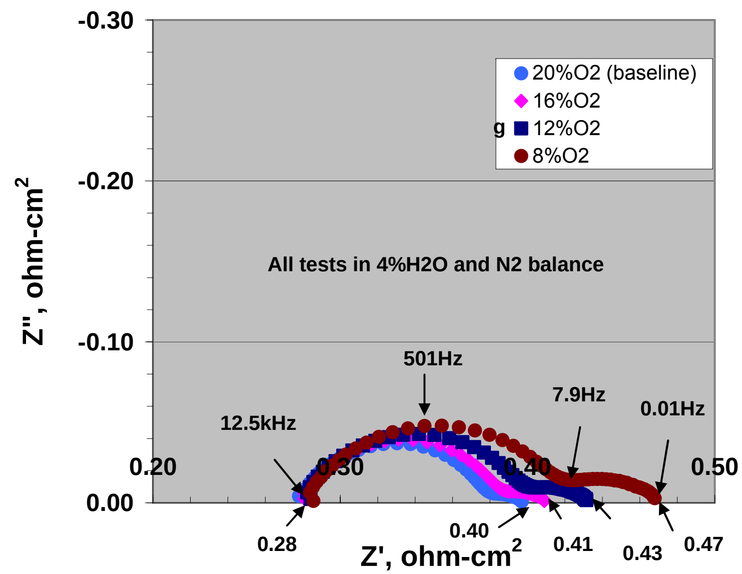




Layer Conductivity Tests

Pressurized Cell Testing





Cathode Button Cell Tests

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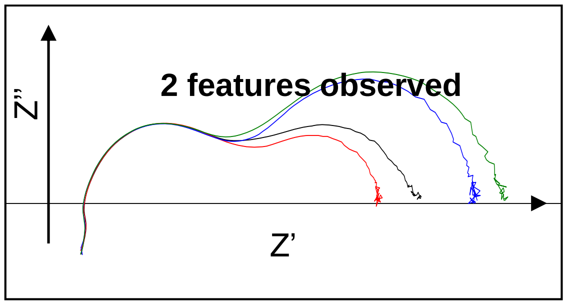
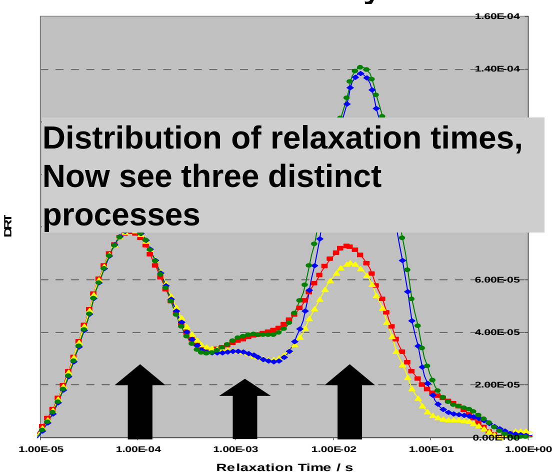
De-convolution of cell performance and degradation contributions

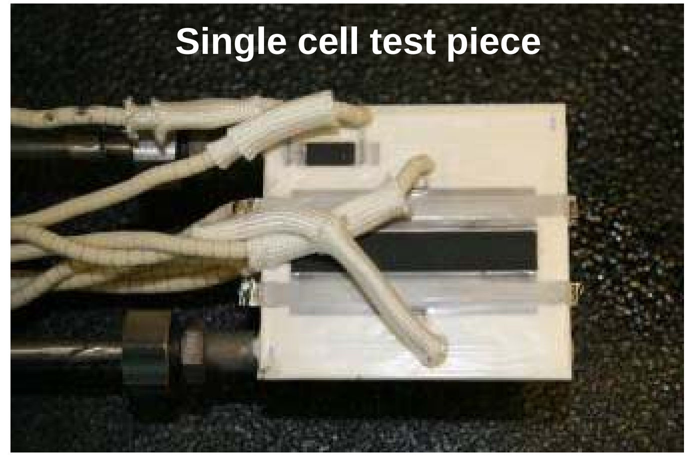
Impossible to de-convolute - only
Ohmic and non-ohmic losses



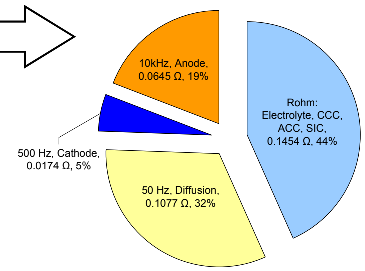
FFT
Analysis



Impedance
spectroscopy
With different fuel
/ oxidant
combinations



Quantify individual
Electrode layers
And ohmic components

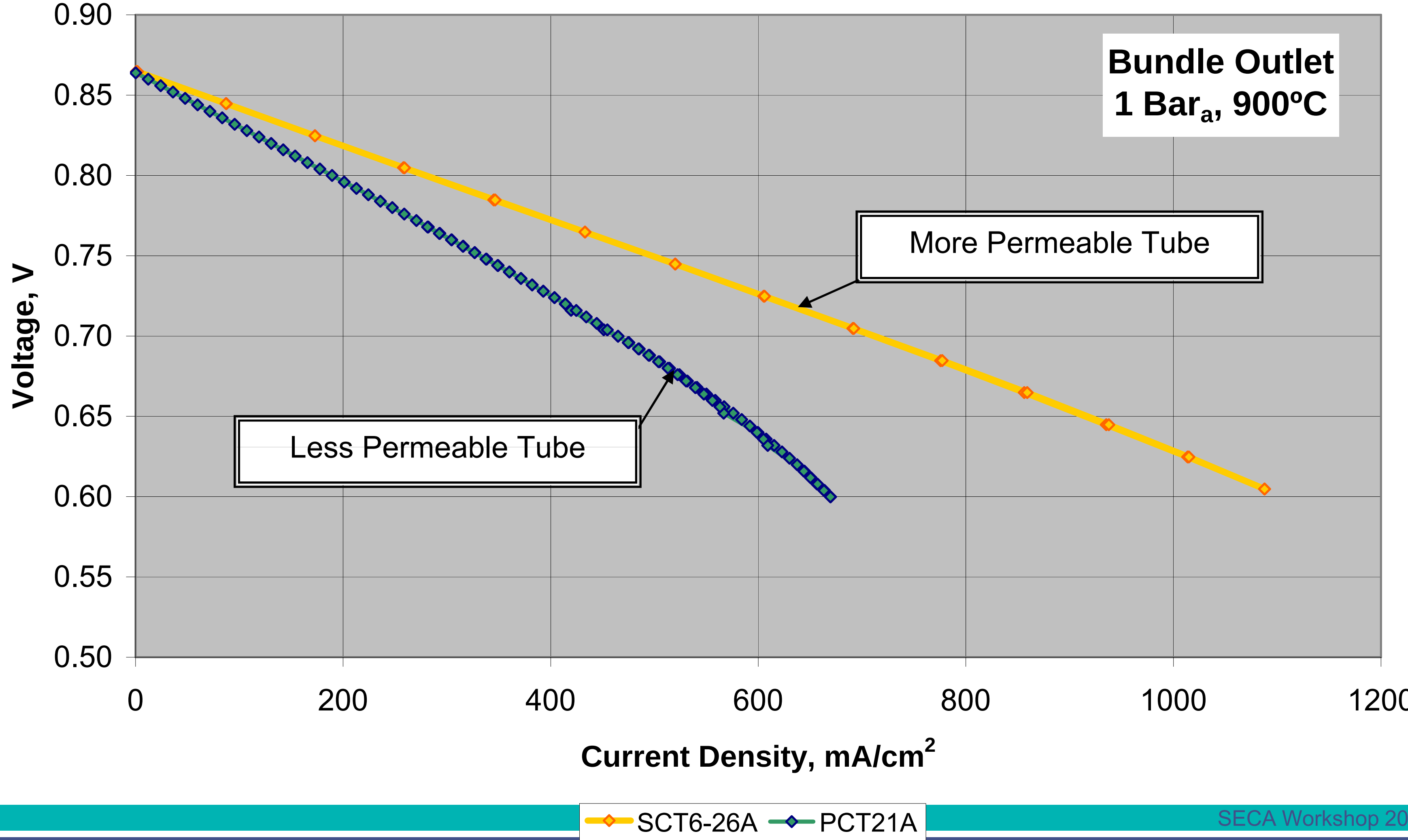


- **Actively drive and monitor degradation**
- **Target individual degradation processes**
- **Door opened to accelerated testing**

Substrate Characteristics Can Impact Electro-Chemical Performance

- Substrate permeability measured to determine diffusional resistance
- Modeling used to relate measured substrate parameters to cell performance

Impact of Diffusion Resistance



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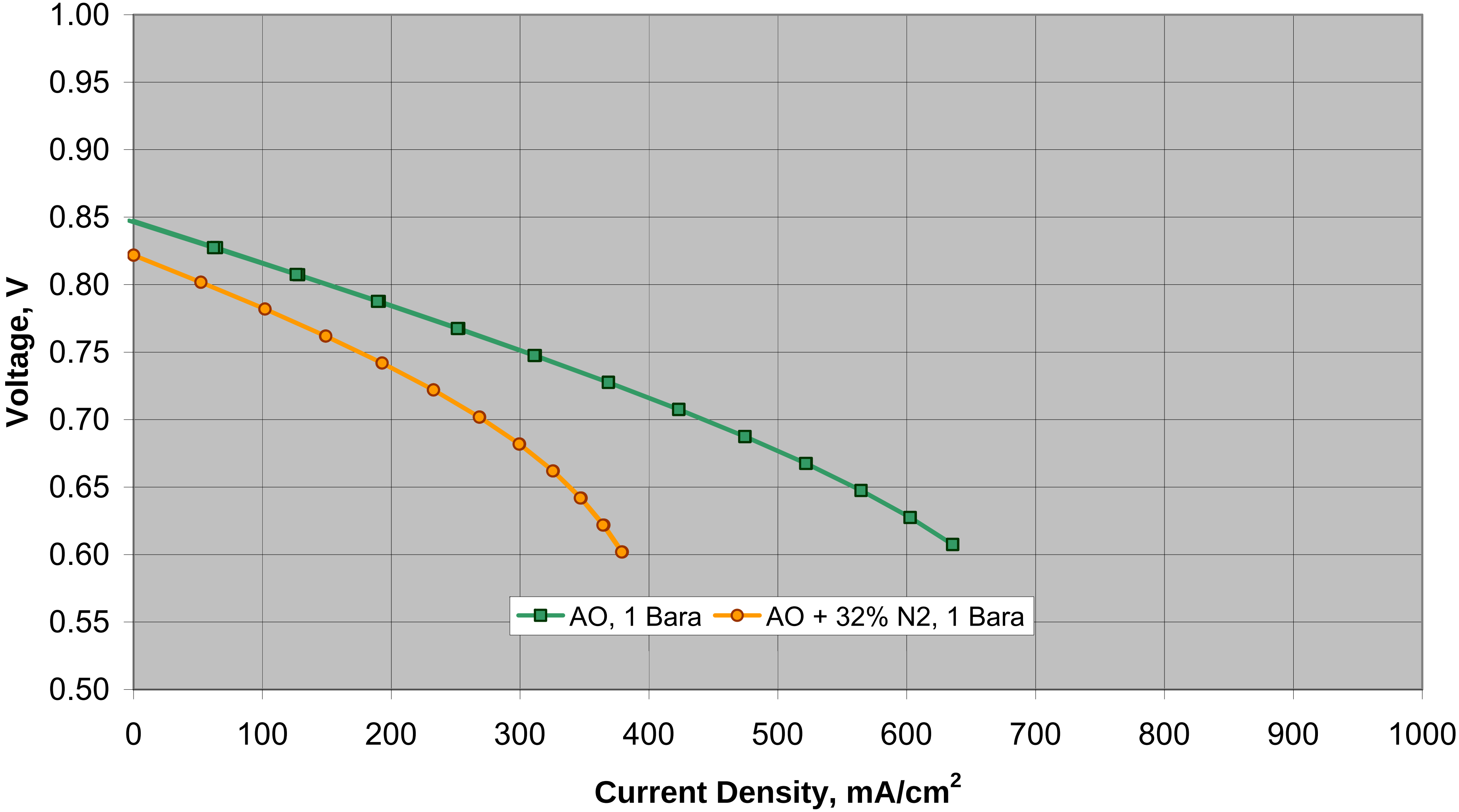
Benefit of Pressure



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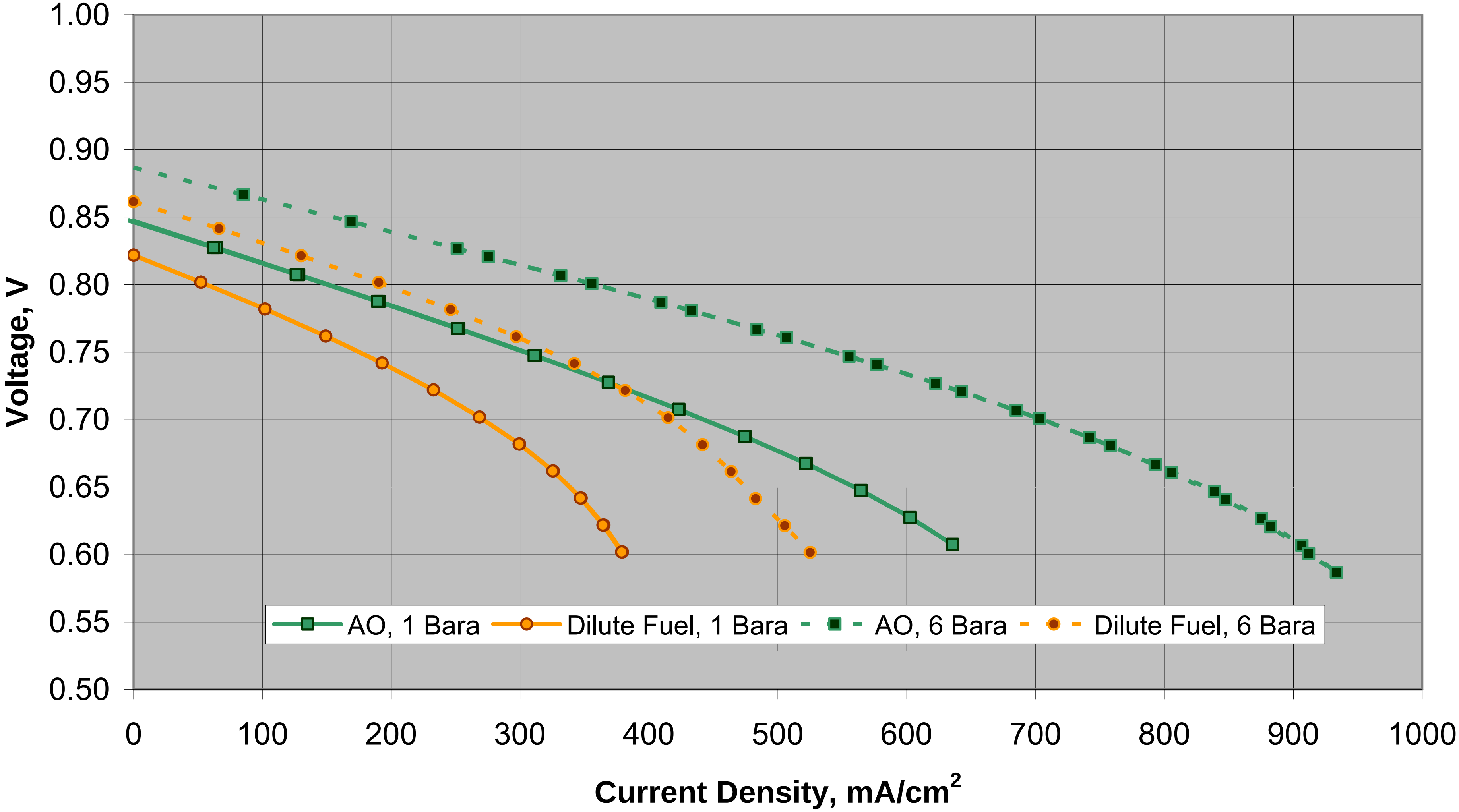
Benefit of Pressure



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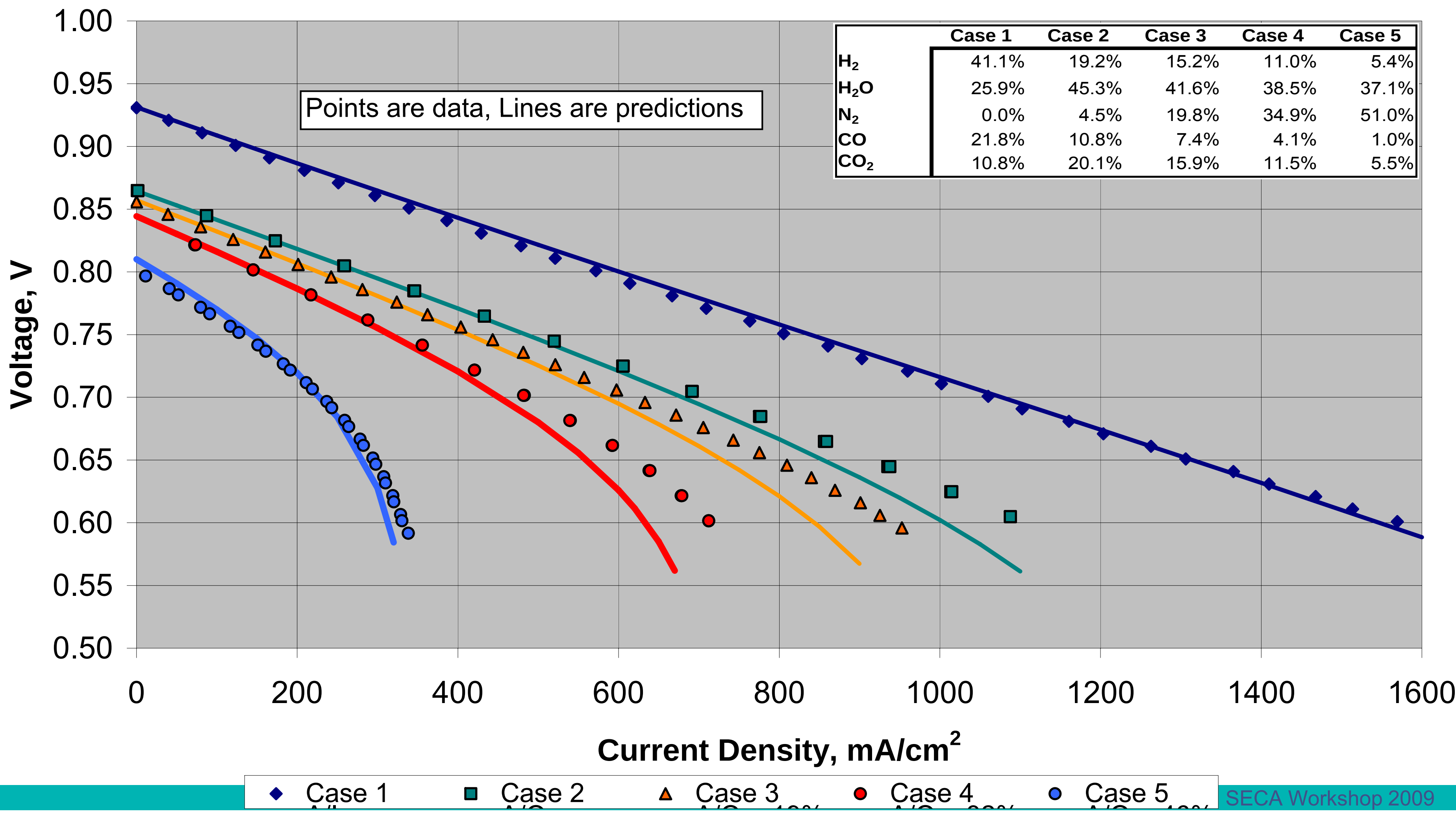
Preliminary Predictions Encouraging



	Case 1	Case 2	Case 3	Case 4	Case 5
H_2	41.1%	19.2%	15.2%	11.0%	5.4%
H_2O	25.9%	45.3%	41.6%	38.5%	37.1%
N_2	0.0%	4.5%	19.8%	34.9%	51.0%
CO	21.8%	10.8%	7.4%	4.1%	1.0%
CO_2	10.8%	20.1%	15.9%	11.5%	5.5%

Rolls-Royce data

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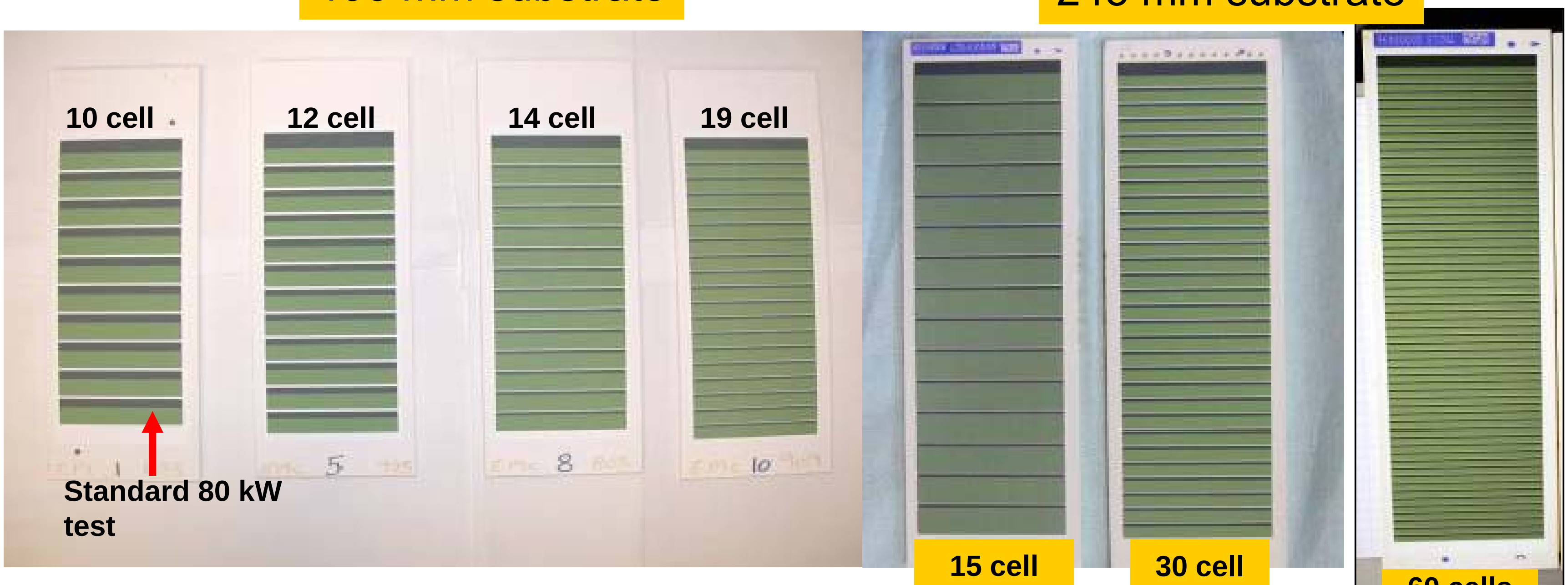
Cell Pitch Optimization

60-cell design minimizes conductance requirement for ACC and CCC

195 mm substrate

245 mm substrate



35%	37%	46%	48%	63%	53%	53%

Active area (% of total surface)

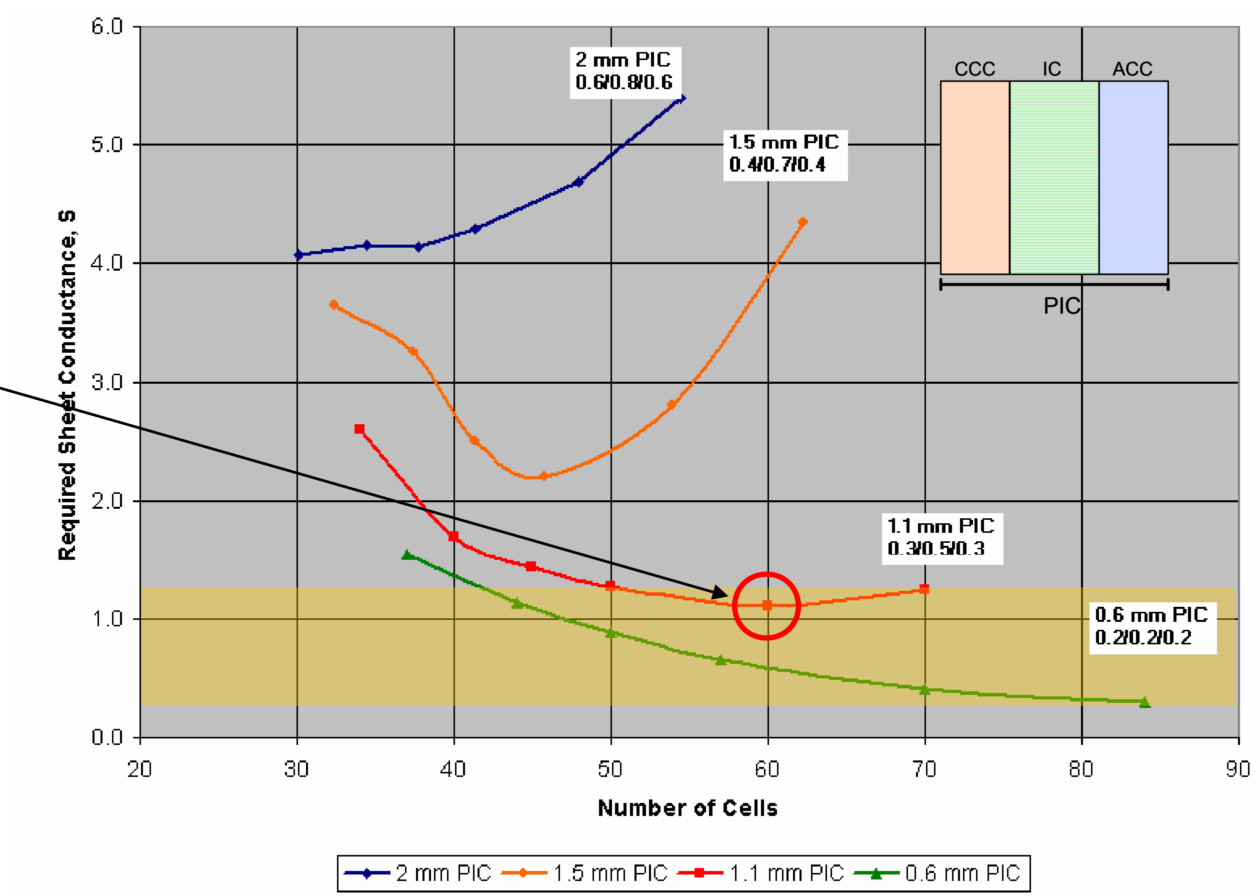
Current design 42W

SECA demonstration 55-60W

Benefits of 60-cell Pitch

- **1.1 mm PIC width selected for lower cost materials**
- **Targeting ~1S ACC and CCC Conductance**
- **Power density = 350 mW/cm²**

Map to Achieve 60W



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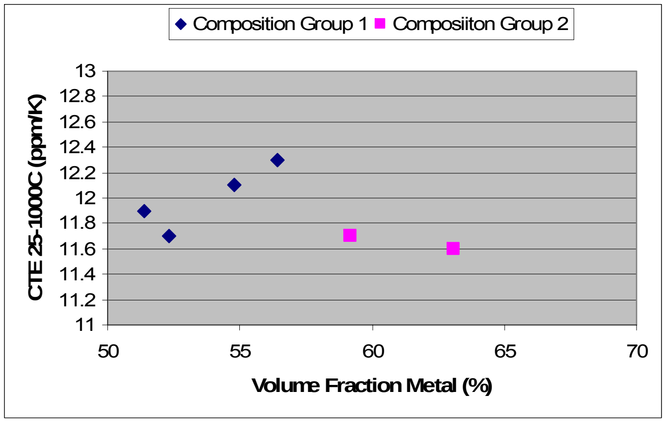
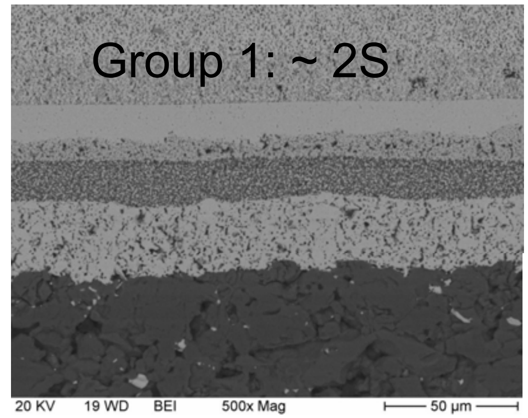
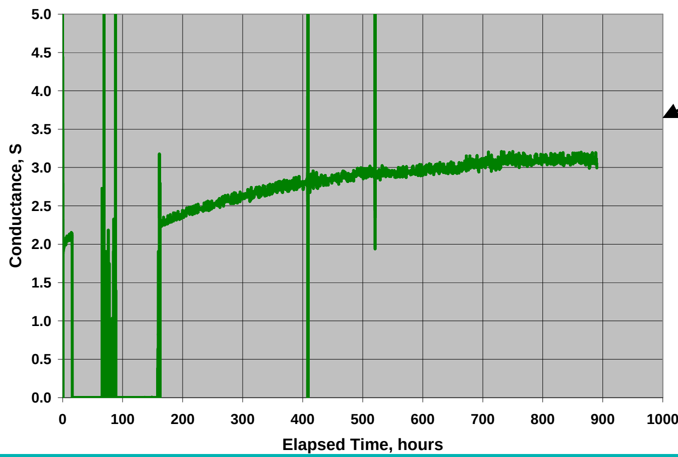
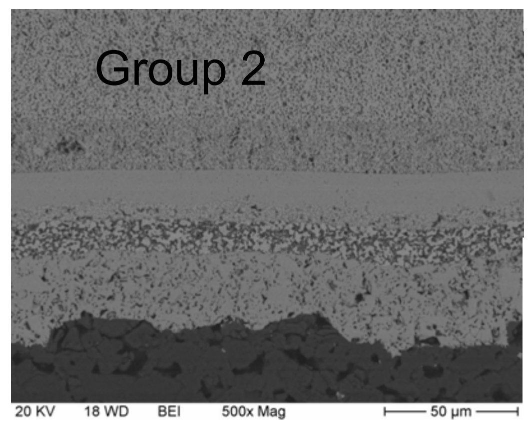
Anode Current Collector

- **Minimize CTE mismatch with substrate**
- **Maximize conductivity within CTE limits**

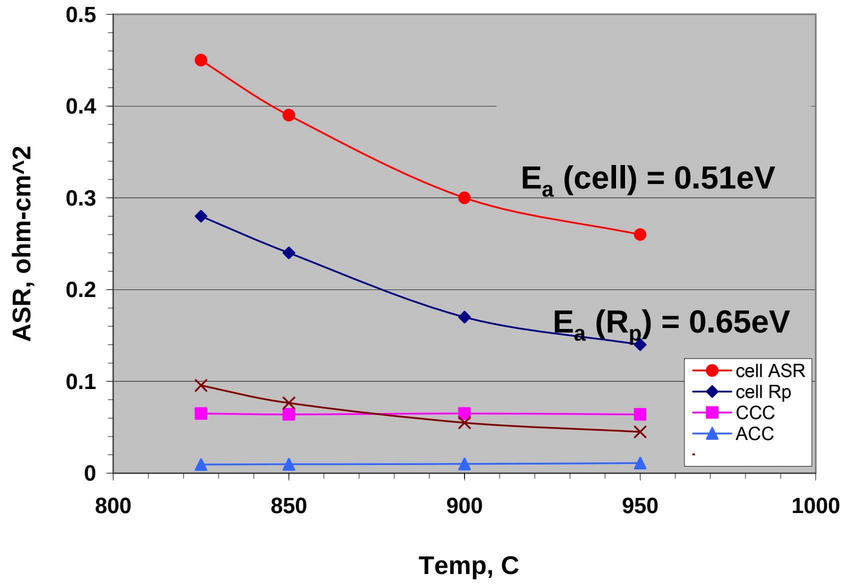


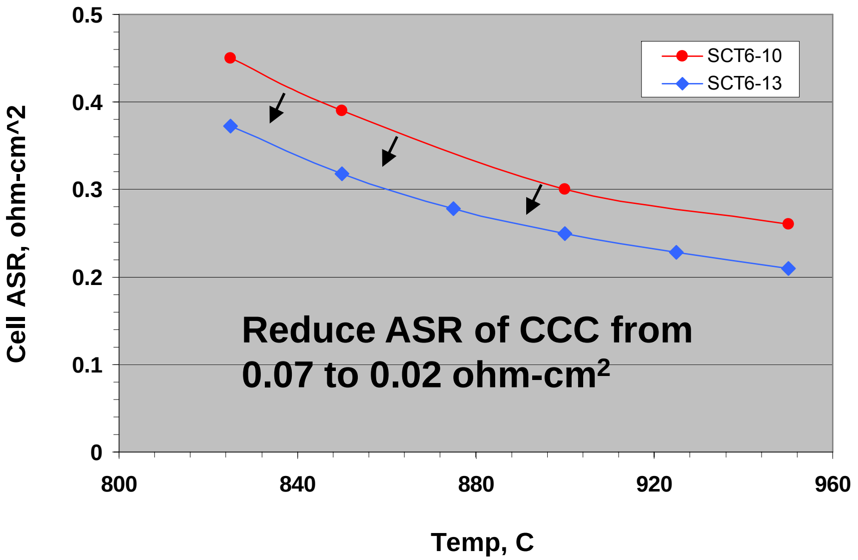


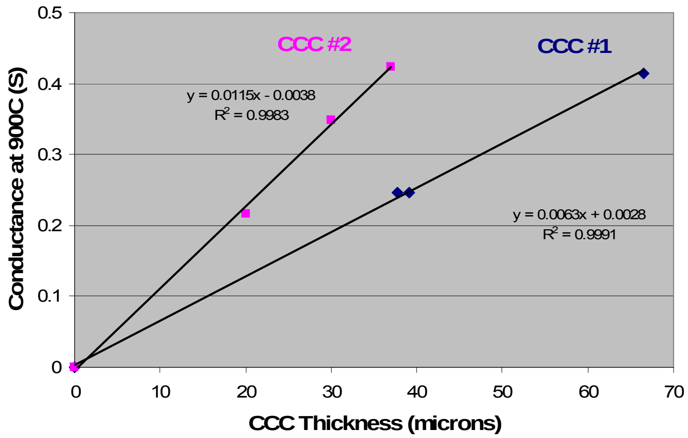




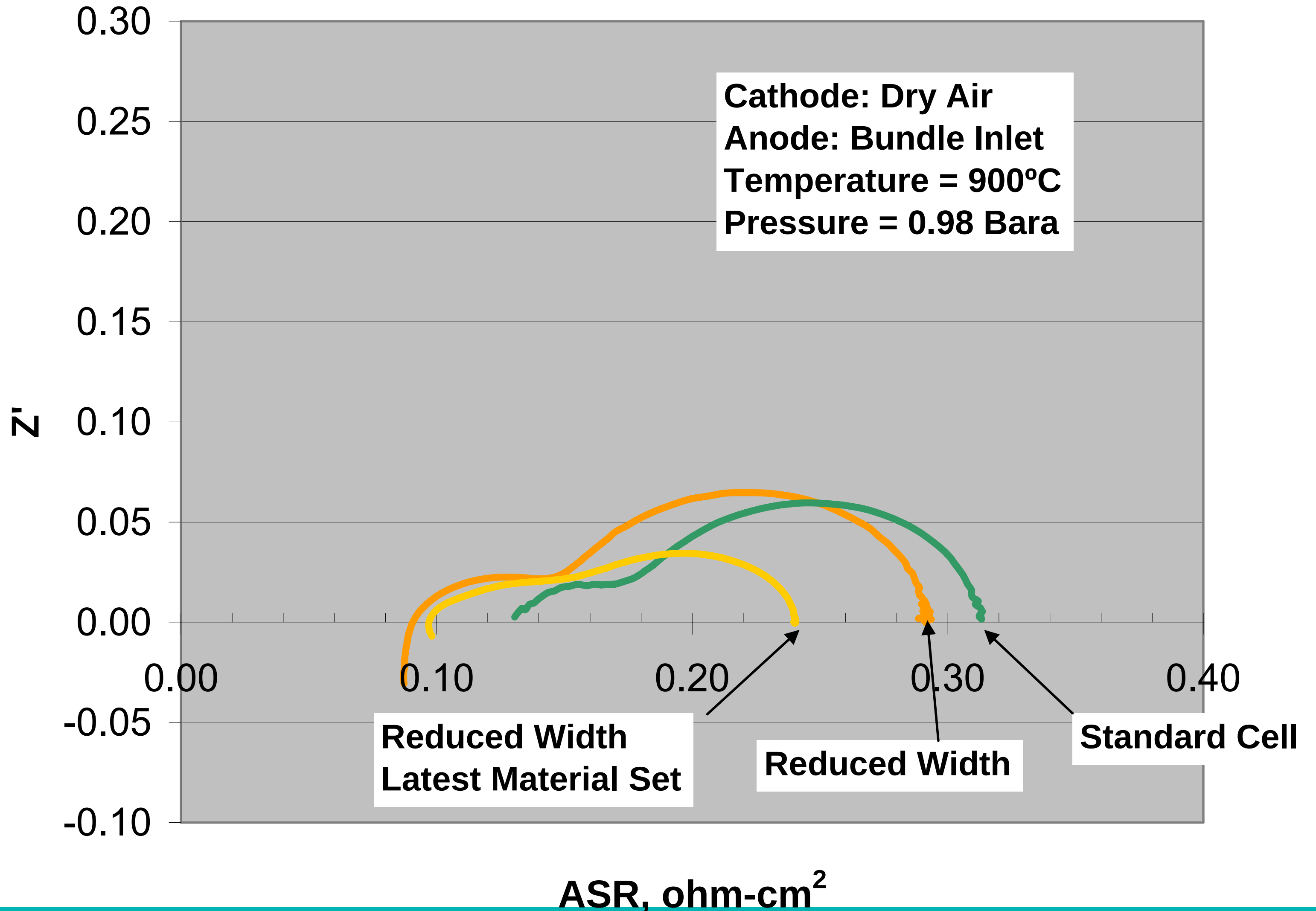
Optimization of CCC Ohmic losses critical to hitting ASR targets



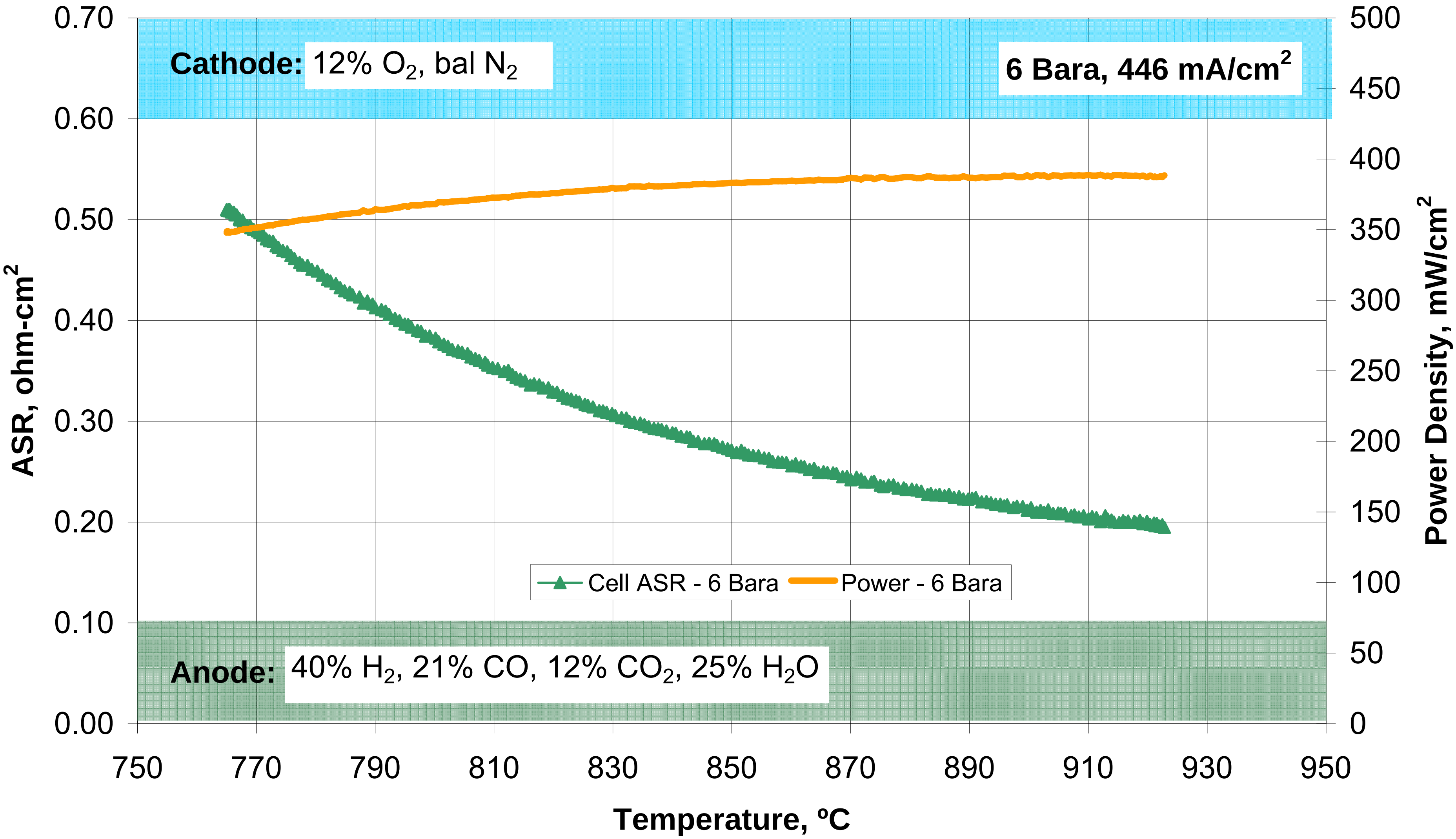




Lower Cost, Better Performance



Latest Single-Cell Performance



Rolls-Royce data

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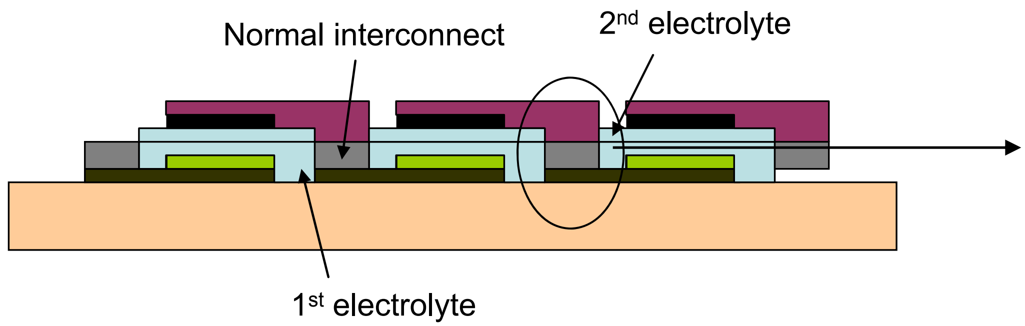
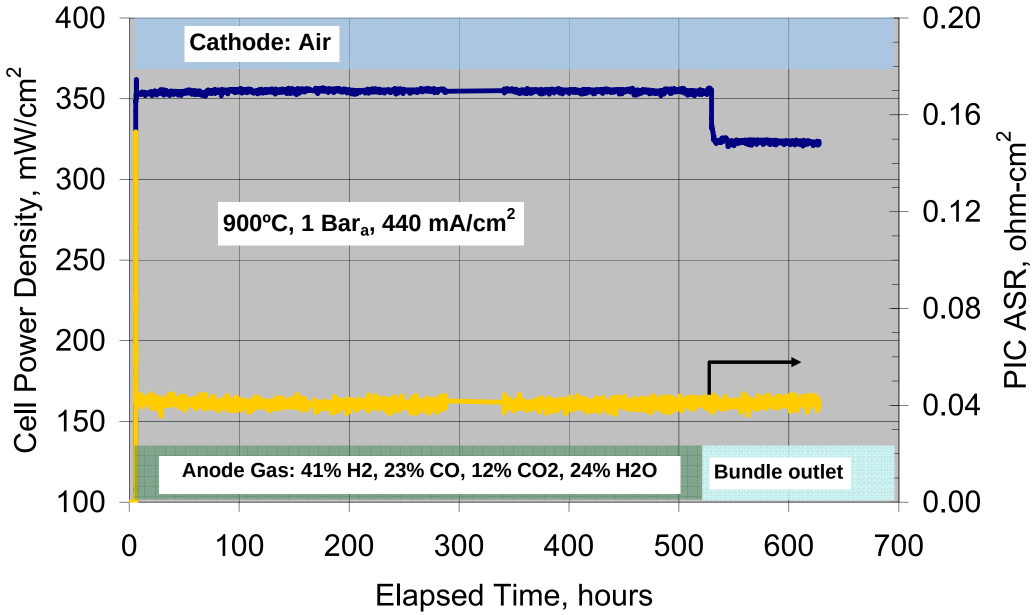
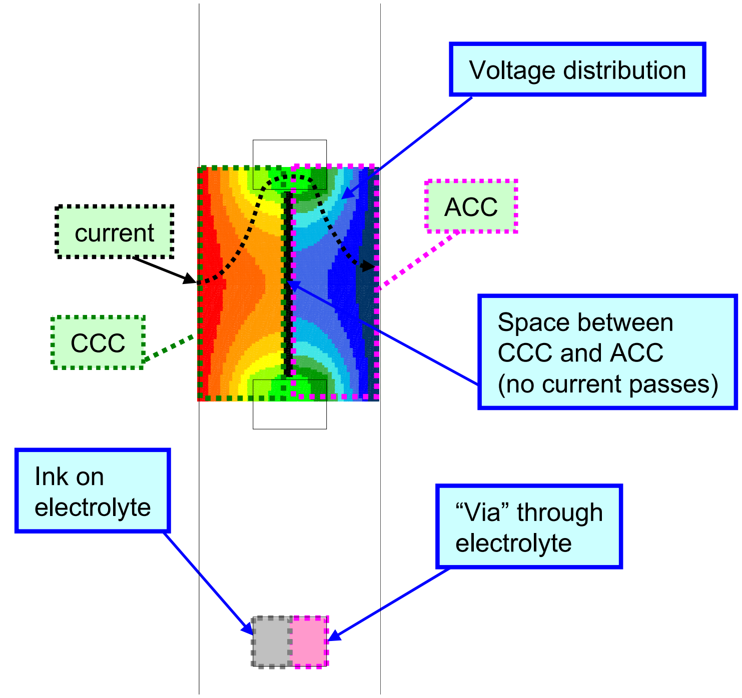
Primary Interconnect ASR: Via-based design



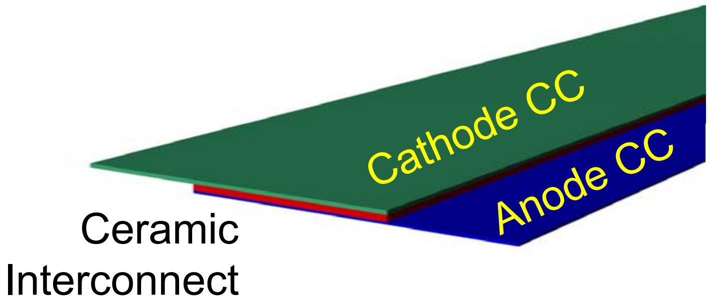


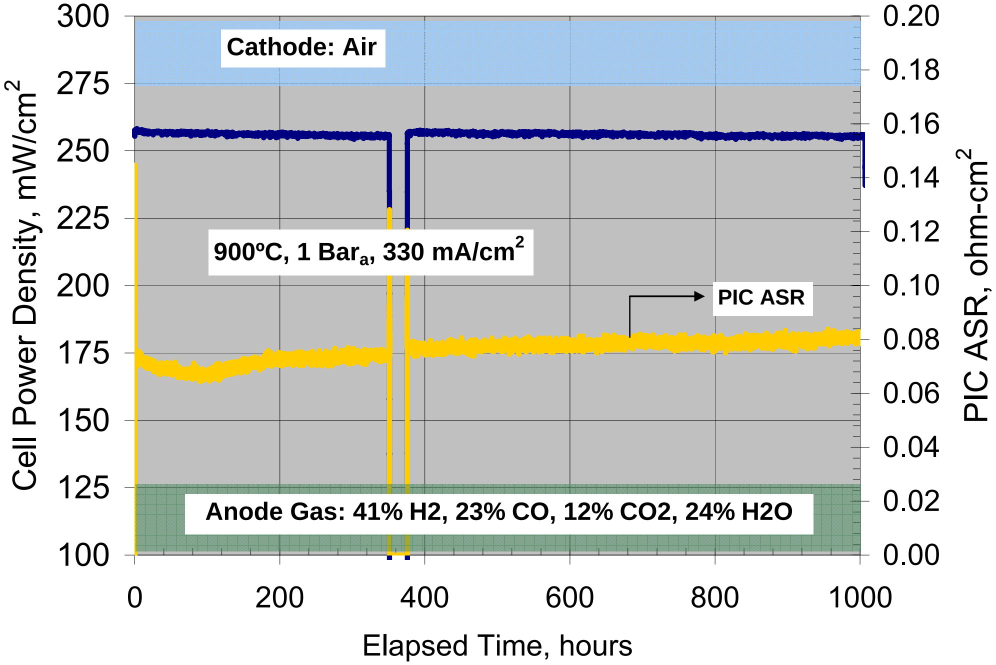


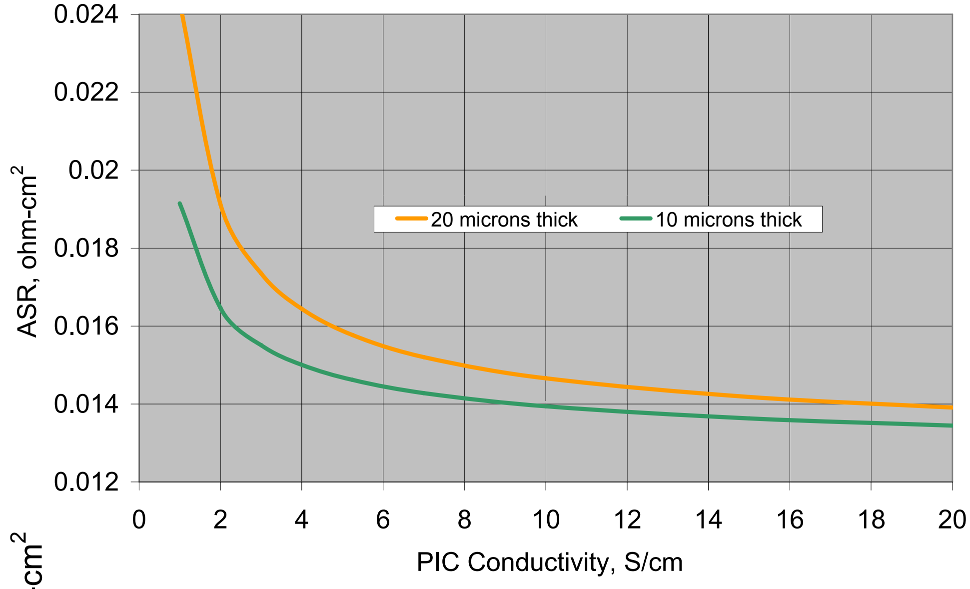
Conductivity model for PIC ASR

PIC ASR=0.032ohm-cm^2

Primary Interconnect ASR: Ceramic Strip based design



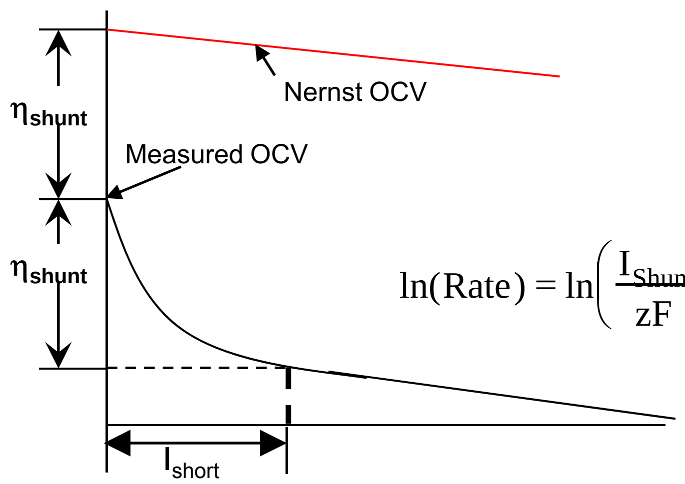




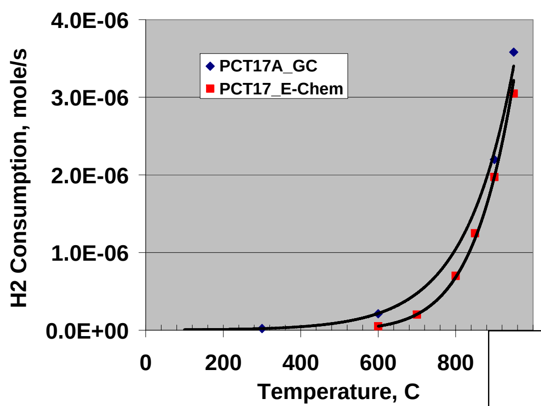
Ceramic interconnect showing feasibility but further optimization required

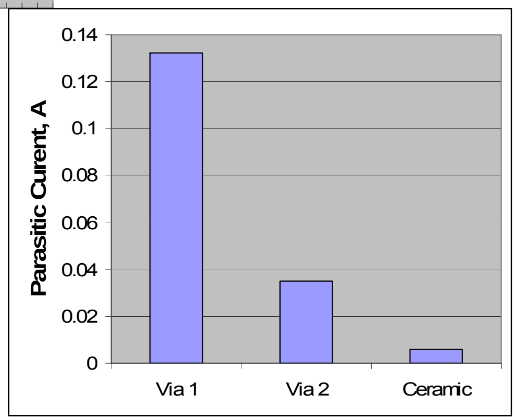
Interconnect Parasitic Losses

- At 60-cell design there is a larger interconnect/cell area ratio
- Must manage local parasitic losses resulting from materials selection, PIC designs and printing accuracy
- Significant improvements achieved through various modifications



$$\ln(\text{Rate}) = \ln\left(\frac{I_{Shunt}}{zF}\right)$$





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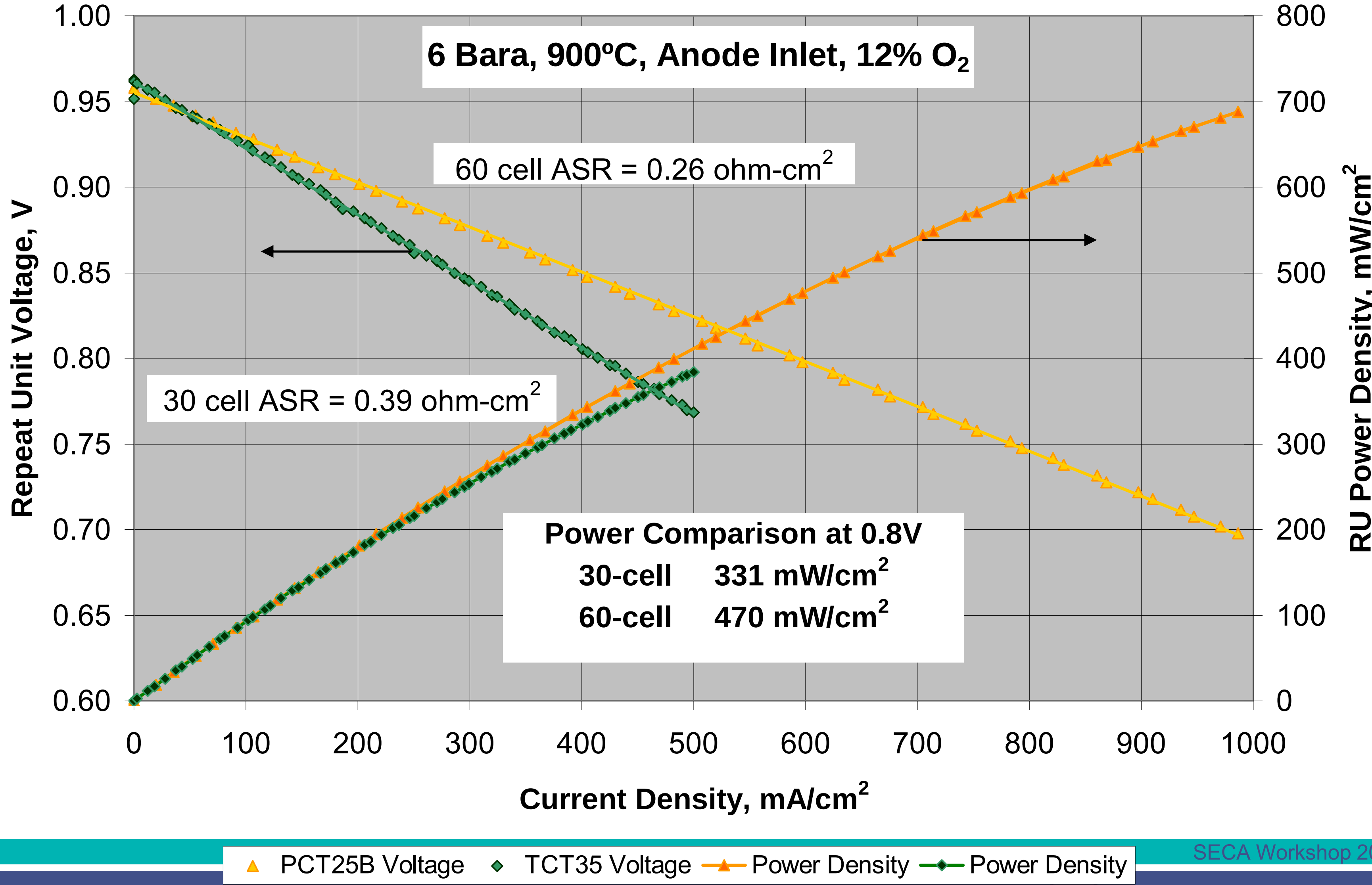
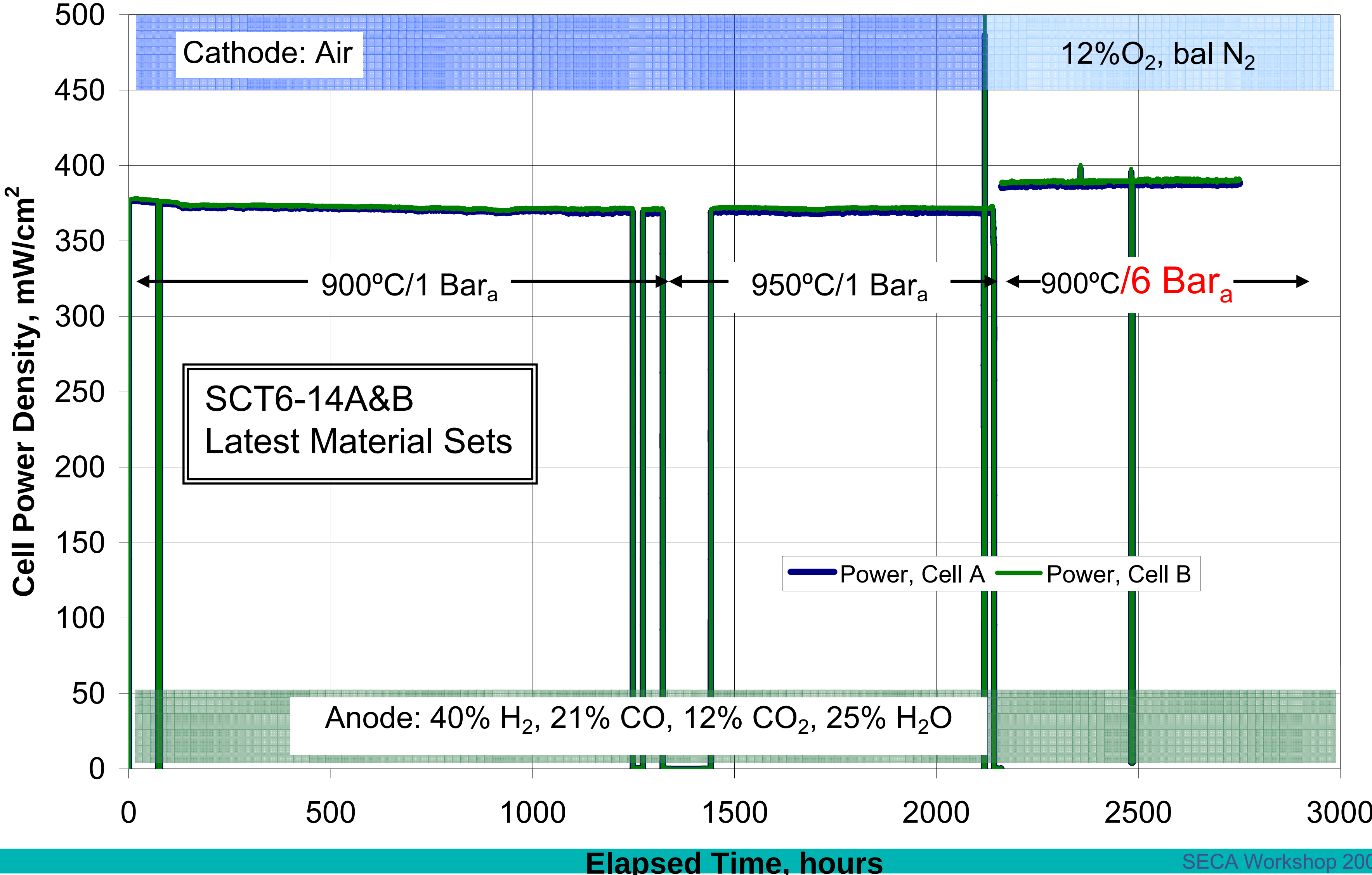
40% Improvement in Power



Single-Cell Degradation Performance



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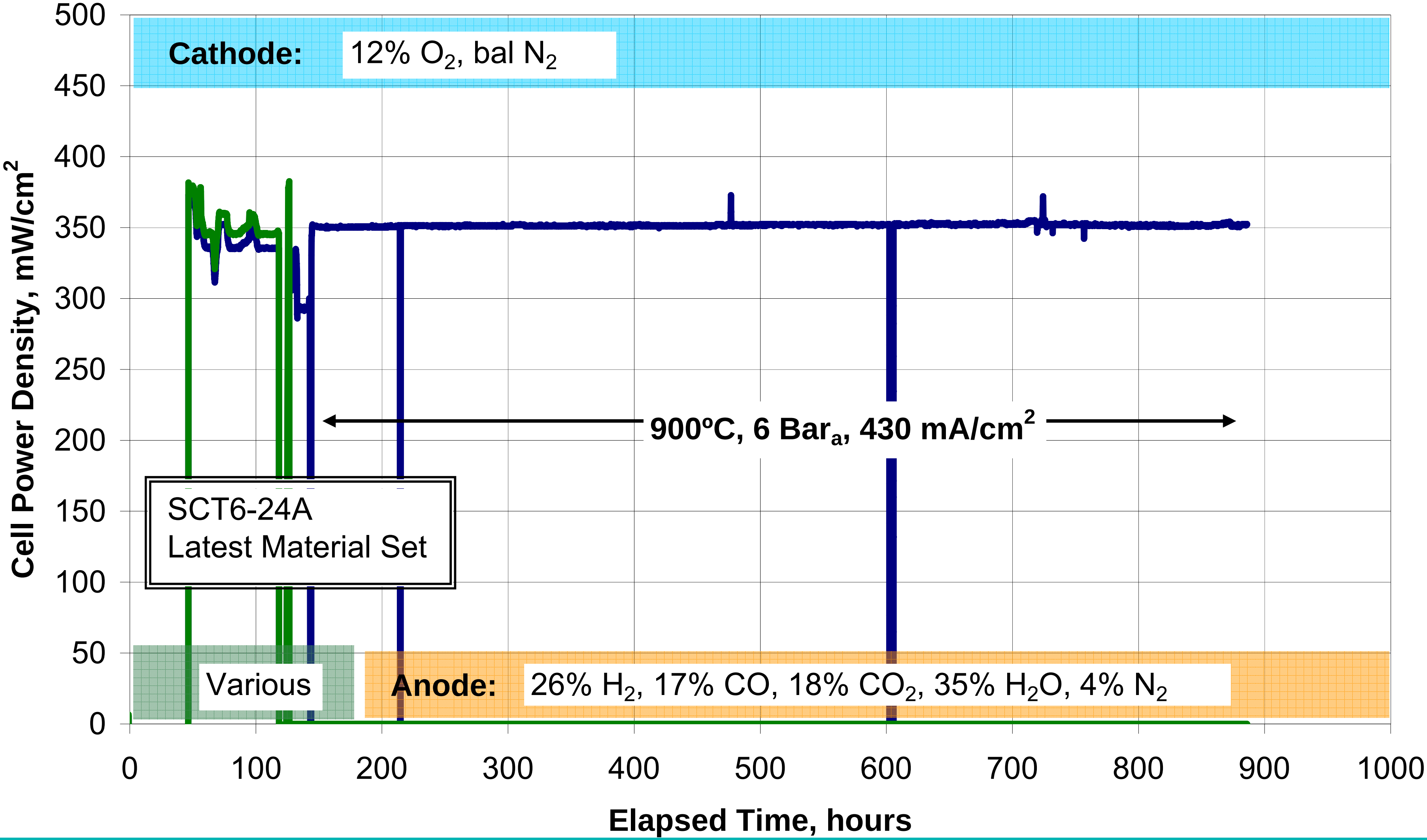
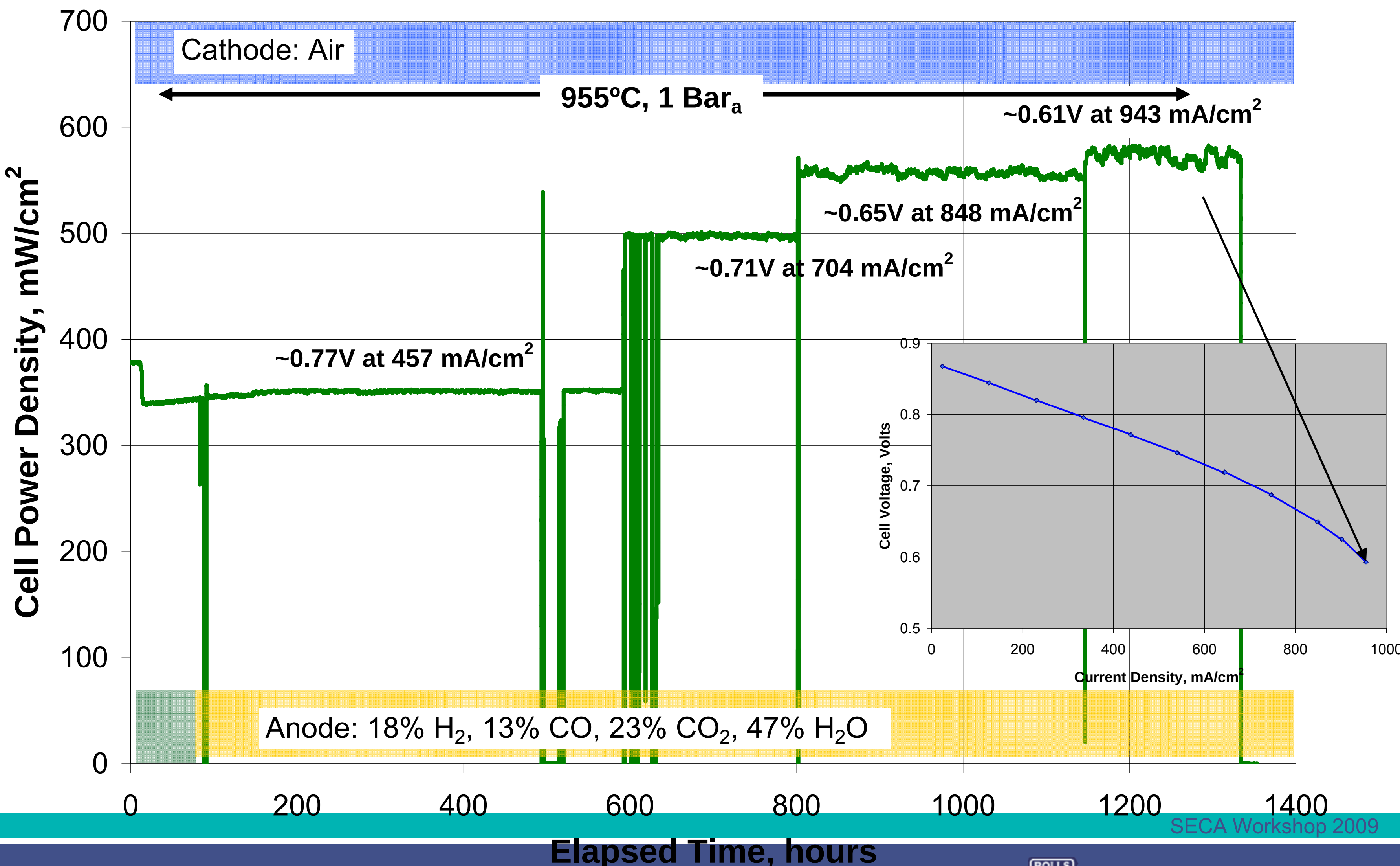


Anode+ACC Candidate #1 Durability

- **Cells can sustain high current density at outlet fuel and 950ºC**



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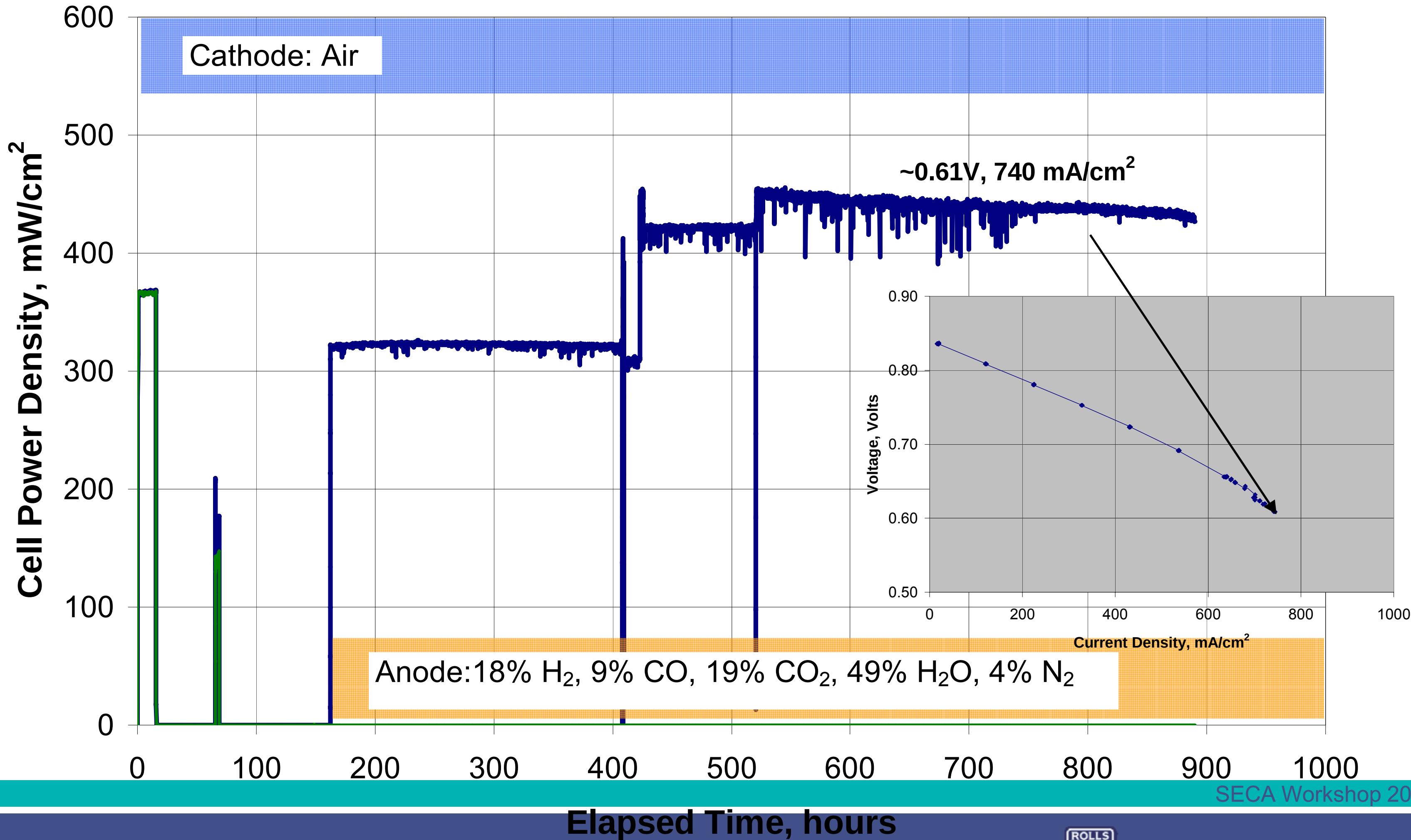
Anode+ACC Candidate #2 Durability

- **This cell displays more diffusive resistance and higher degradation**



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- Scaled tests are demonstrating good performance and durability

Acknowledgements

- This material is based on work supported by the Dept. of Energy National Energy Technology Laboratory under Award Number DE-FC26-08NT0003893
- RRFCS project manager Travis Shultz and the entire SECA program management team
- UK and US based RRFCS team

Thank You
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